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METHOD AND DEVICE FOR FORMING THE INTENSITY PROFILE OF A LASER BEAM

Technical Field

The present invention relates to a method and a device for forming the intensity profile of a laser beam, in particular for producing a homogeneous intensity profile, as well as to the use of an optically addressable spatial light modulator (OASLM) for forming the intensity profile of a laser beam.

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Background of the Invention

The physical properties of laser light differ fundamentally from those of conventional light sources. Laser light is coherent and can be produced as a light beam having a small, even if finite aperture angle. This narrow beam concentration is particularly advantageous for illumination and imaging purposes, since the wave fronts of the laser light approach the ideal of plane waves. They are very easily transformed into spherical wave fronts and can be utilized for highly resolving, diffraction-limiting focusing.

One drawback of the laser beam is its Gaussian character, which is determined by the manner in which light is generated in the resonator. The intensity distribution of the light transversely to the beam has the shape of a Gaussian bell curve. This means that the intensity is at a maximum in the middle of the beam, and it then drops off exponentially toward the edges.

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This is particularly disadvantageous in image processing and projection technologies which require illuminating flat photomasks. However, it is also a drawback in interferometry, where a most uniform possible illumination of the lighted surface is critical. Such uniformity is not provided when working with a Gaussian intensity profile. In material processing as well, such as in medical applications involving heating of tissue, or in laser welding, uniform heating is required over the entire width of the laser beam or of the illuminated surface. Such uniform heating cannot be attained when working with a Gaussian shaped illumination and, thus, for instance a Gaussian energy deposition. For that reason, the cross-sectional profile of the light beam should be as rectangular as possible for the areas of application mentioned. The spatial intensity profile should be homogeneous, i.e., more or less constant over a certain width. To effect this, in practice, the beam is widened and one then works only with the more or less homogeneous, inner beam region, the outer region being masked out. However, this leads to significant intensity losses.

Since the actual laser system, the optical amplification medium in the resonator, is not accessible to the user, the forming of the beam into a rectangular profile must take place outside of the laser. For this purpose, optical filters, so-called "bull's eye" filters are known, which attenuate the laser beam more vigorously in the middle than at the edges, thereby flattening the bell shape of the beam profile to a virtually rectangular profile. For the most part, these filters are made of a

transparent plate, e.g., a glass plate, upon which a more or less reflectiv coating, for example a metal, is coated by vapor deposition. The desired beam profile is produced by properly selecting the locally dependent optical density, i.e., the local transmission and reflection properties. These filters are static and, therefore, can only be used for a specific laser having a fixed, known intensity profile. When the laser changes its profile, e.g., due to fluctuations or manifestations of aging, the filters undesirably alter the shape of the profile, since they are no longer adapted to the laser data. Another disadvantage associated with reflecting filters of this kind is that unevenly reflected laser light has a reactive effect on the laser and can degrade its stability. Moreover, in place of reflecting filters, it is also generally known to use holographic filters for forming beams (I. Gur et al.: Diffraction limited domain flat-top generator; Opt. Communications 145, 237 (1998)). These filters are also static and are not responsive to time-related changes in the laser beam profile. Also problematic is the fact that the rectangular profile is only produced in the imaging plane of the holographic element.

Technical Objective

The underlying objective of the present invention is, therefore, to form the most homogeneous possible, rectangular beam profile from any initial intensity profile at all, in particular from a Gaussian beam profile, the intention being for the formed beam profile to be substantially stable with respect to fluctuations

in the incident intensity profile and in the light intensity.

Detailed Description of the Invention

The objective is achieved by a method for forming the intensity profile of a laser beam, in particular for producing a homogeneous intensity profile, the laser beam striking an optically addressable spatial light modular (OASLM), whose local transmission or reflection properties depend in nonlinear fashion on the local illumination intensity.

A device in accordance with the present invention for forming the intensity profile of a laser beam, in particular for producing a homogeneous intensity profile, is composed of an optically addressable spatial light modular (OASLM), whose local transmission or reflection properties depend in nonlinear fashion on the local illumination intensity, as well as of at least one telescope imaging system, which is capable of spatially widening the laser beam.

Furthermore, the objective is achieved by the use of an optically addressable spatial light modular (OASLM) for forming the intensity profile of a laser beam, in particular for producing a homogeneous intensity profile.

The present invention provides a beam former, i.e., a method for forming beams, where the formed intensity profile is stabilized with respect to changes in the original intensity profile through the use of an active

or adaptive optical element having optical properties that are dependent upon the local illumination intensity. In particular, an optical element is used, whose local transparency changes with the local illumination intensity. A defined beam profile, which is virtually independent of fluctuations in the initial intensity distribution, is automatically produced. In principle, this is done without any additional controlling external influence. For that reason, the method and the beam former, respectively, can be used for any laser systems at all, and only need to be adapted to a minor degree to prevailing conditions.

In accordance with the present invention, the optically non-linear element is an optically addressable spatial light modulator (OASLM) or liquid crystal light valve. It is preferably driven in the saturation range to produce a homogeneous (rectangular) laser beam profile; the locally transmitted intensity is then independent of the local illumination intensity.

Optically addressable spatial light modulators (OASLM) are known, for example, from "Spatial Light Modulators; OSA - Technical Digest ISBN 155752-494-7 Washington 1997" which are made of a photoconductive layer and of an electro-optical, voltage-sensitive layer. In response to local irradiation, the voltage in the photoconductor breaks down locally and is transferred to the electro-optical layer. On a localized basis, this alters the transmission or reflection characteristics of the electro-optical layer, which, in turn, is now optically indicative of the irradiation. The photoconductive layer

must be sensitive to the wavelength of the incident light. The electro-optical layer is, for example, a liquid crystal, which has optical modulator properties within broad spectral ranges. Certain materials unite the properties of the photo-sensitive and voltage-sensitive layer, such as photorefractive crystals or polymers (Spatial Light Modulators; OSA - Technical Digest ISBN 155752-494-7 Washington 1997, M. Petrov et al.: Photorefractive Crystals, Berlin 1991).

In accordance with the present invention, liquid crystals which have nonlinear optical properties are used in OASLMs. The OASLM is based, for example, on nematic or helical smectic liquid crystals, the latter having an operating frequency of 10^2 to 10^3 Hz, thereby facilitating faster reactions to output profile changes than do elements based on nematic liquid crystals (switching times in the range of 10^{-2} s). The modulation properties of these liquid crystals depend nonlinearly on the applied voltage and, thus, on the local illumination intensity 1 on the photoconductor.

A typical transmission characteristic of an OALSM of this kind is exemplified by a linear relation between the illumination intensity and transmitted intensity for low illumination intensities, as well as by a transition into the saturation range, where the transmitted intensity is virtually independent of the illumination intensity. For higher intensities, the transmitted intensity can again depend more heavily on the illumination intensity.

The above described properties of an OASLM enable, in

particular, high light intensities to be attenuated more vigorously than low intensities. In this manner, the intensity of a Gaussian beam in the center is suppressed as compared to the edge regions, and the transmitted intensity approaches a rectangular shape having a flat plateau in the center.

One advantageous further refinement of the present invention provides for the OASLM layers to undergo pattern delineation, preferably resolved into individual zones, in particular optical points (pixels), preferably capable of being driven individually. This diminishes crosstalk between nearby picture elements. Finally, this permits electrical intervention in the modulator, on a pixel-by-pixel basis, in particular an adaptation of the local transmission properties, targeted to the initial intensity profile. One can advantageously regulate the driving of the individual zones by measuring the shaped beam profile and examining it for deviations from a nominal form, in particular from the rectangular form. By way of a feedback path, the magnitude of the local deviations is then used as a basis for adapting the transmission properties of the zones or of the picture elements of the OASLM.

To work in the saturation region of the OASLM, the intensity of the laser beam to be shaped is preferably adapted by widening the beam and/or through the use of optical filters at the saturation region of the OASLM. For purposes of beam widening, an optical imaging system is preferably inserted into the optical path of rays, within which the OASLM is located. The optical imaging

system preferably encompasses two telescope imaging systems, preferably designed as mechanically or electrically adjustable or controllable zoom systems. Thus, the beam widening is variable, so that changes in intensity can always be compensated by intensity fluctuations of the laser or by replacing the laser.

Brief description of the drawing, illustrating:

Figure 1 a typical transmission characteristic of an OASLM

Figure 2 three set-ups according to the present invention for forming a beam, with the use of an OASLM

Figure 1 schematically depicts a typical transmission characteristic of an OASLM, as used in accordance with the present invention, the incident intensity being plotted on the x-axis and the transmitted intensity on the y-axis. For low intensities, the OASLM has a substantially linear transmission characteristic, for example, it is essentially transparent to the incident radiation. For higher incident intensities, the transmitted intensity is substantially independent of the incident intensity; this saturation range is selected as the working range for the beam formation. The intensity of the incident laser beam to be formed is adapted to this working range by filters or by widening the beam. In this context, the advantage of widening the beam is that, once it has passed through the OASLM, the light is able to be focused again, so that there is minimal loss of total intensity.

Three set-ups are shown in Figures 2a-c for forming a

beam in accordance with the present invention, using an OASLM. Figure 2a illustrates a set-up where the OASLM is inserted between two coupler telescopes 1, 2, into the laser's path of rays. Telescopes 1, 2 each include two lenses having focal lengths f_1, f_2 and f_1', f_2', respectively, arranged at a distance of f_1+f_2 and $f_1'+f_2'$, respectively. The telescopes are used for beam widening, to reduce the intensity in the laser beam center to the point where it coincides with the plateau region of the characteristic in accordance with Figure 1. The laser beam having the flattened beam profile exits the second telescope 2 to the right. If it is necessary to simultaneously widen the beam, the right telescope 2 must have a smaller magnification than the left telescope 1.

In certain cases, for example once a laser is coupled into an optical fiber, the laser intensity can already be optimally adapted to the OASLM. Without any previous widening, the light can then be directly conducted to the OASLM, as shown in Figure 2b. The light from fiber 3 then falls directly on beam former OASLM, which can be in optical contact with fiber 3. Reflection losses experienced during the transition into the OASLM, are able to be kept to a minimum in this case by using an oil to adapt the refraction index. The advantage of this specific embodiment is that the OASLM can have an especially small type of construction.

When one is experiencing heavy fluctuations in laser intensity, or when the intention is to use the same beam former for different types of lasers, it is recommended to connect two zoom telescopes 5, 6 instead of telescopes

having fixed magnifications, as in Figure 2a. This is shown schematically in Figure 2c. In this case, the beam widening can be altered and, given electrically adjustable zoom telescopes, also controlled.

Industrial Applicability

The present invention has many diverse industrial applications. In particular, it is advantageously employed in applications where the most uniform possible illumination of surfaces by laser light is critical, especially when working with image processing and projection technology, in interferometry, as well as in material processing where the use of lasers is required.